STUDY OF LITHIUM DOPED SOLAR CELLS

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Second Quarterly Report

from

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ABSTRACT

In the second quarter, increased understanding was gained of the effects of various lithium diffusion schedules on cell behavior. Included is a summary of one shipment of 60 cells delivered to JPL for testing.

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1.0 INTRODUCTION

This program is intended to determine the properties of silicon solar cells doped with lithium, and to study the process parameters giving optimum post irradiation recovery and good cell stability.

Work continued on evaluating the effects of various lithium diffusion cycles on different forms of silicon. An overall picture of the spatial lithium distributions after various cycles was obtained by probing, and the accompanying changes in I-V characteristics were followed.

2.0 TECHNICAL DISCUSSION

2.1 LITHIUM INTRODUCTION METHODS

Most work this quarter used oil suspensions of lithium. The capacity of the diffusion boat was increased, allowing uniform diffusion for twenty four 2 cm^2 cells per run.

Additional work on vacuum evaporation still gave a greater spread in cell characteristics than the paint-on method.

No work was performed on lithium vapor methods in this period, but more is scheduled.

2.2 LITHIUM CONCENTRATION PROFILES

It is convenient to define three kinds of lithium diffusion cycle, each giving a characteristic type of lithium distribution. These cycles are:

(a) Tack-On - The diffusion cycle consists of a low temperature or a short time, forming a thin layer of lithium, several mils thick (see Figure 1).

(b) Drive-In - The diffusion temperature or time exceeds that in (a), while the lithium source is maintained in contact with the silicon. A thick layer heavily doped with lithium is formed (see Figure 2).

(c) Redistribution - After (a) or (b), the slices are cooled, the excess lithium is removed from the slice, and the slice is given an additional diffusion cycle. If redistribution follows (a), the profile changes as shown in Figure 3; if redistribution follows (b), Figure 4 shows the profile changes.

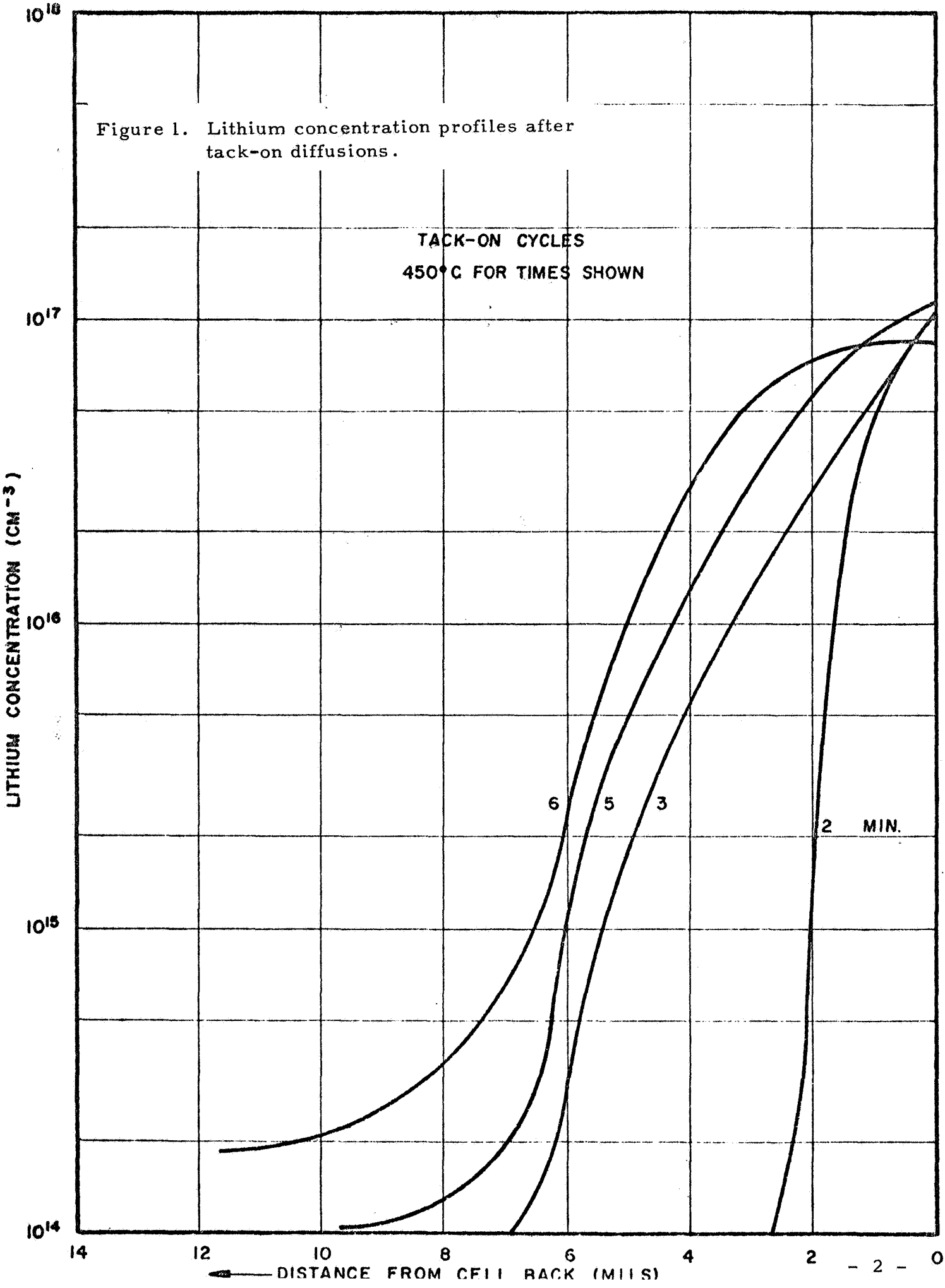


Figure 1. Lithium concentration profiles after tack-on diffusions.

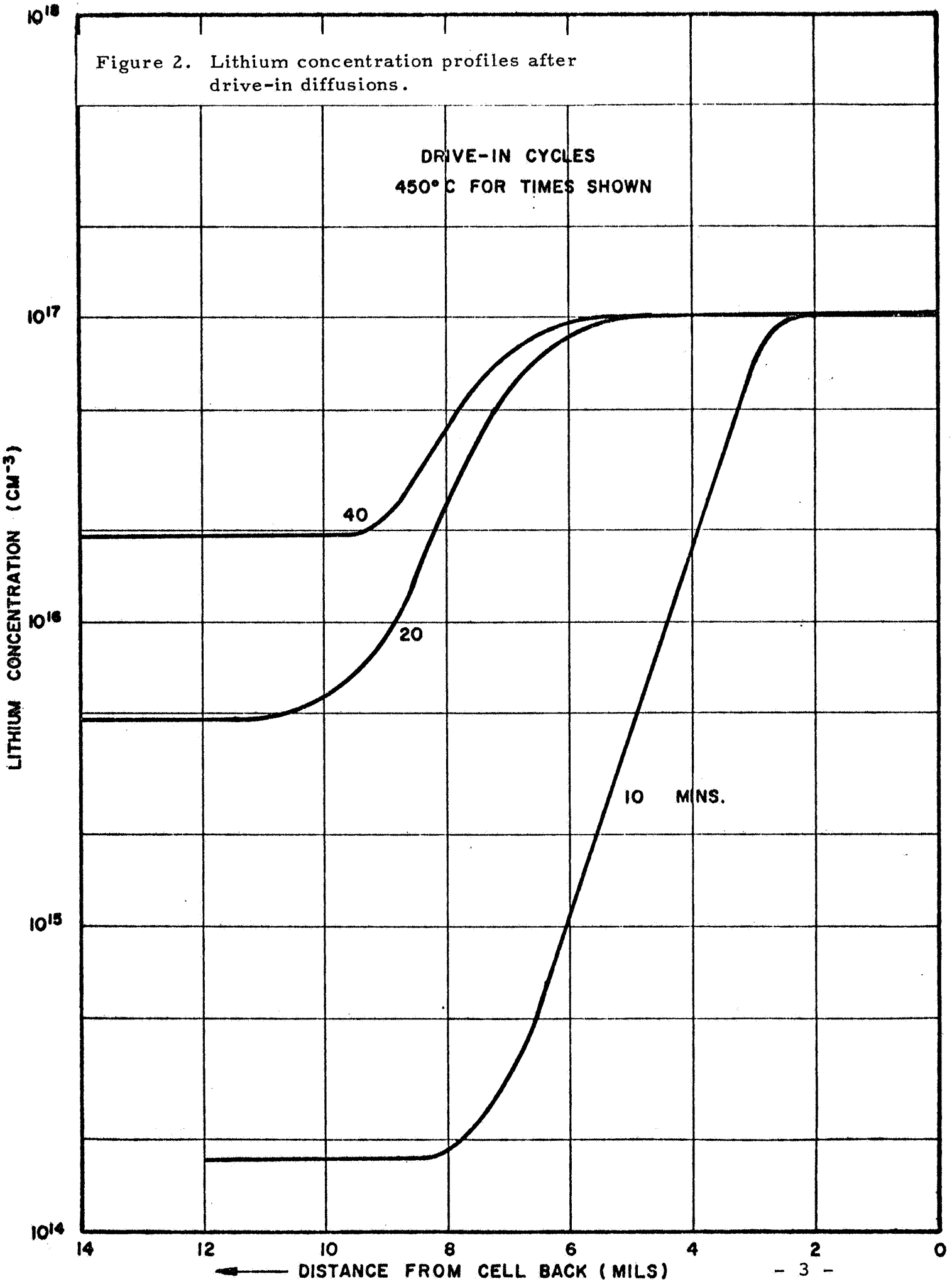
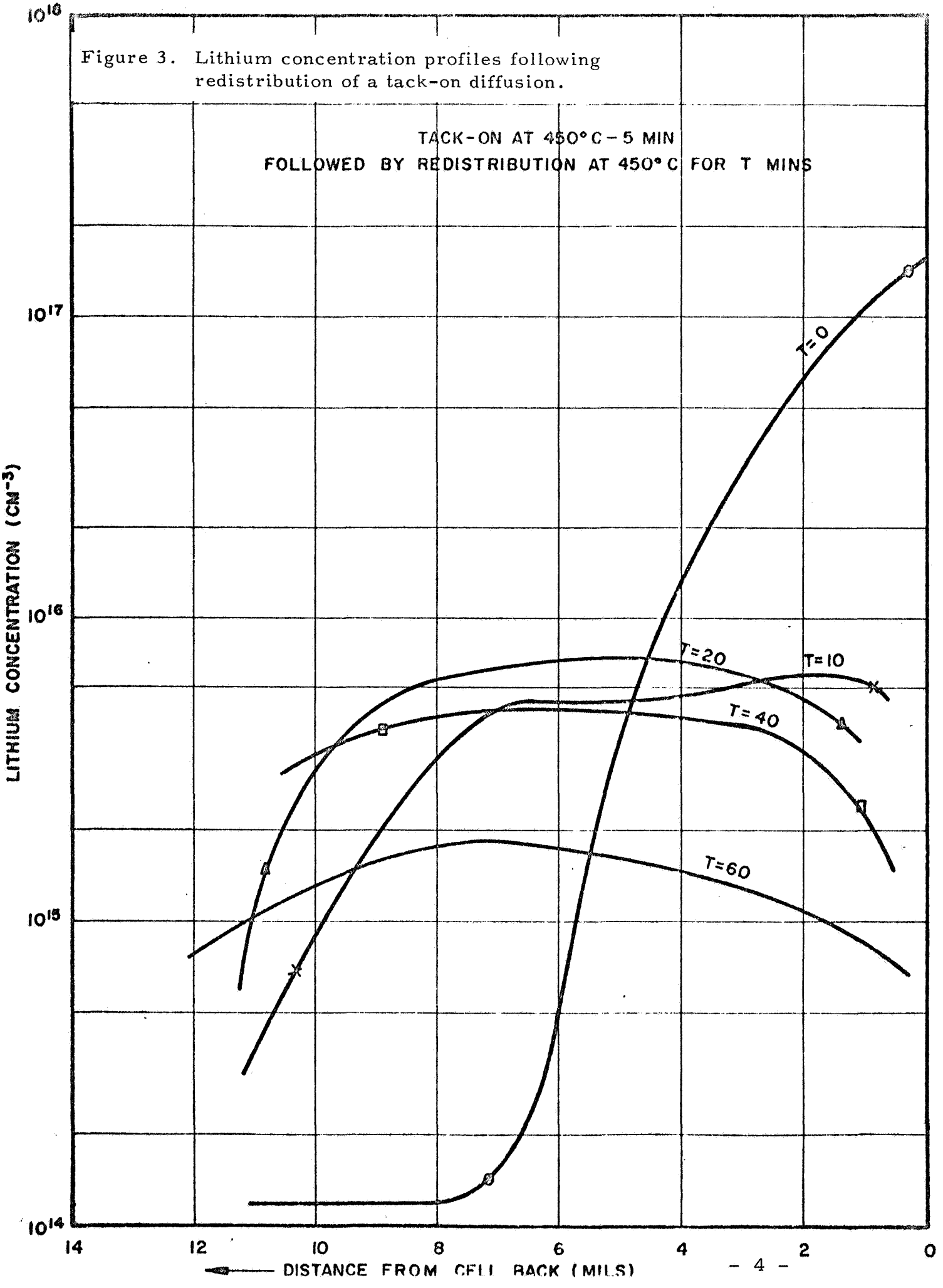


Figure 2. Lithium concentration profiles after drive-in diffusions.

Figure 3. Lithium concentration profiles following redistribution of a tack-on diffusion.



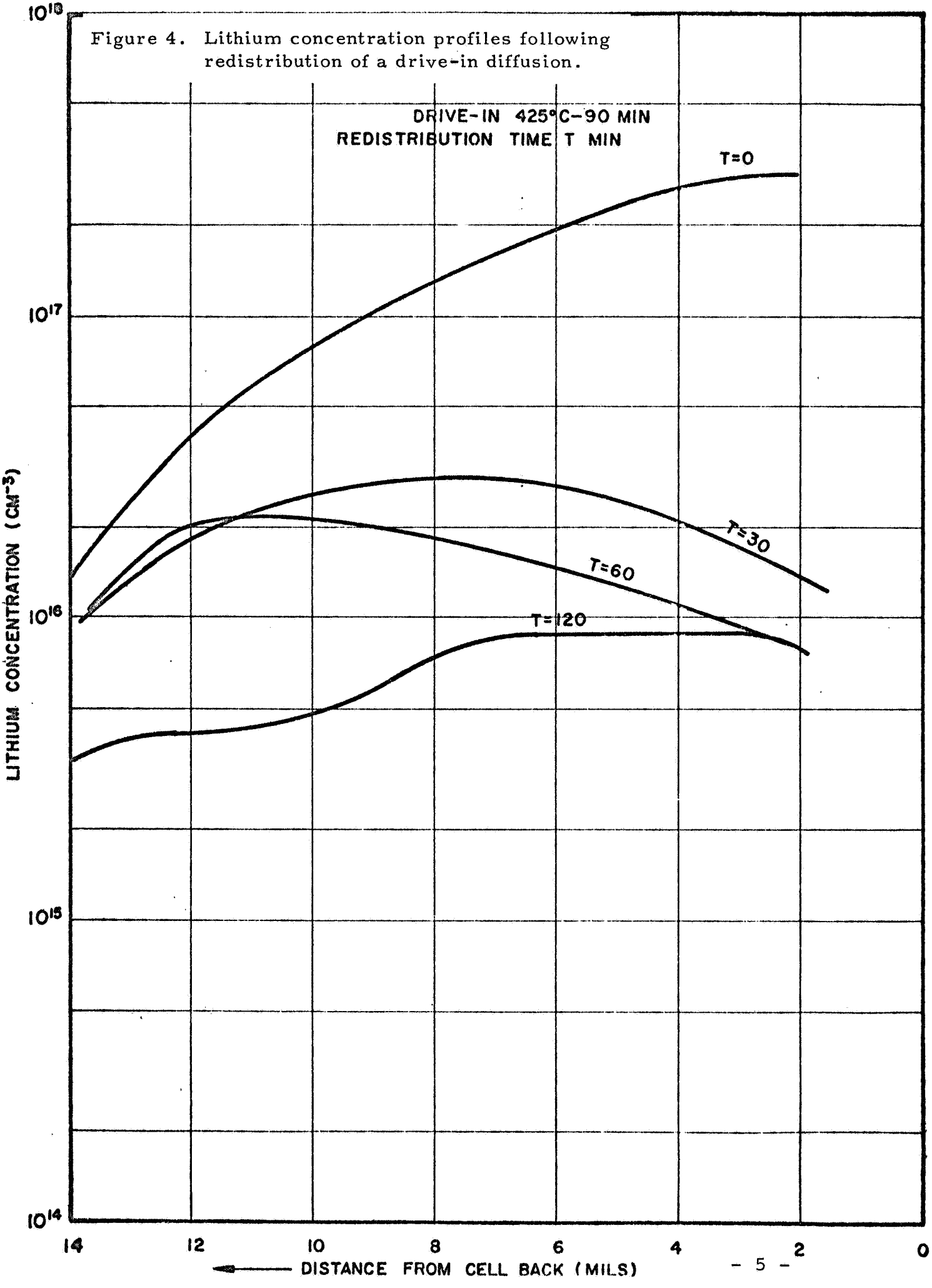


Figure 4. Lithium concentration profiles following redistribution of a drive-in diffusion.

2.2 LITHIUM CONCENTRATION PROFILES (Continued)

Under some conditions, a redistribution cycle can produce a more uniform lithium distribution through the cell. However, the lithium concentration is generally lower near the major surfaces. The loss near the back surface may result from out-diffusion, that near the front surface from dissolution of lithium in the diffused boron layer. The concentration profiles shown are plotted on log-linear scales, and this disguises the extent of the variations. If, after various redistribution cycles the active donors are summed (by integrating under a linear plot of concentration versus distance), serious overall losses of lithium are found; typically for 30 minutes redistribution at 450°C, the lithium content falls by 70% for crucible-grown silicon, and 40% for float-zone silicon.

These profiles show that many different diffusion cycles introduce lithium concentrations above 10^{15} cm^{-3}, thus converting most of the bulk N-silicon to low resistivity (< 1 ohm-cm) silicon. Solar cells with such doping generally behave as expected. V_{OC} values range from 560 mV to 600 mV, and the series resistance is low. The capacitance, dark diode characteristics, A-values and temperature coefficients are also typical of low resistivity silicon.

An interesting feature of lithium cells is that the collected current depends on the amount of lithium near the PN junction, higher concentrations reducing I_{SC} (see Figures 5 and 6). Examination of the changes in lithium concentration after redistribution (Figures 3 and 4) shows that after a tack-on cycle, I_{SC} should steadily decrease with redistribution whereas after a drive-in cycle, redistribution should increase I_{SC}. These changes are found in practice (Figure 7). V_{OC} is much less sensitive to these changes in lithium concentration.

2.3 LITHIUM DIFFUSION TESTS

Some lithium diffusion runs were carried out at 600°C. The resulting cells had low I_{SC}, although I_{SC} increased after redistribution.

Figure 5. Isc versus lithium concentration near the PN junction. Cell area 2cm^2, space sunlight 140 mw/cm^2.

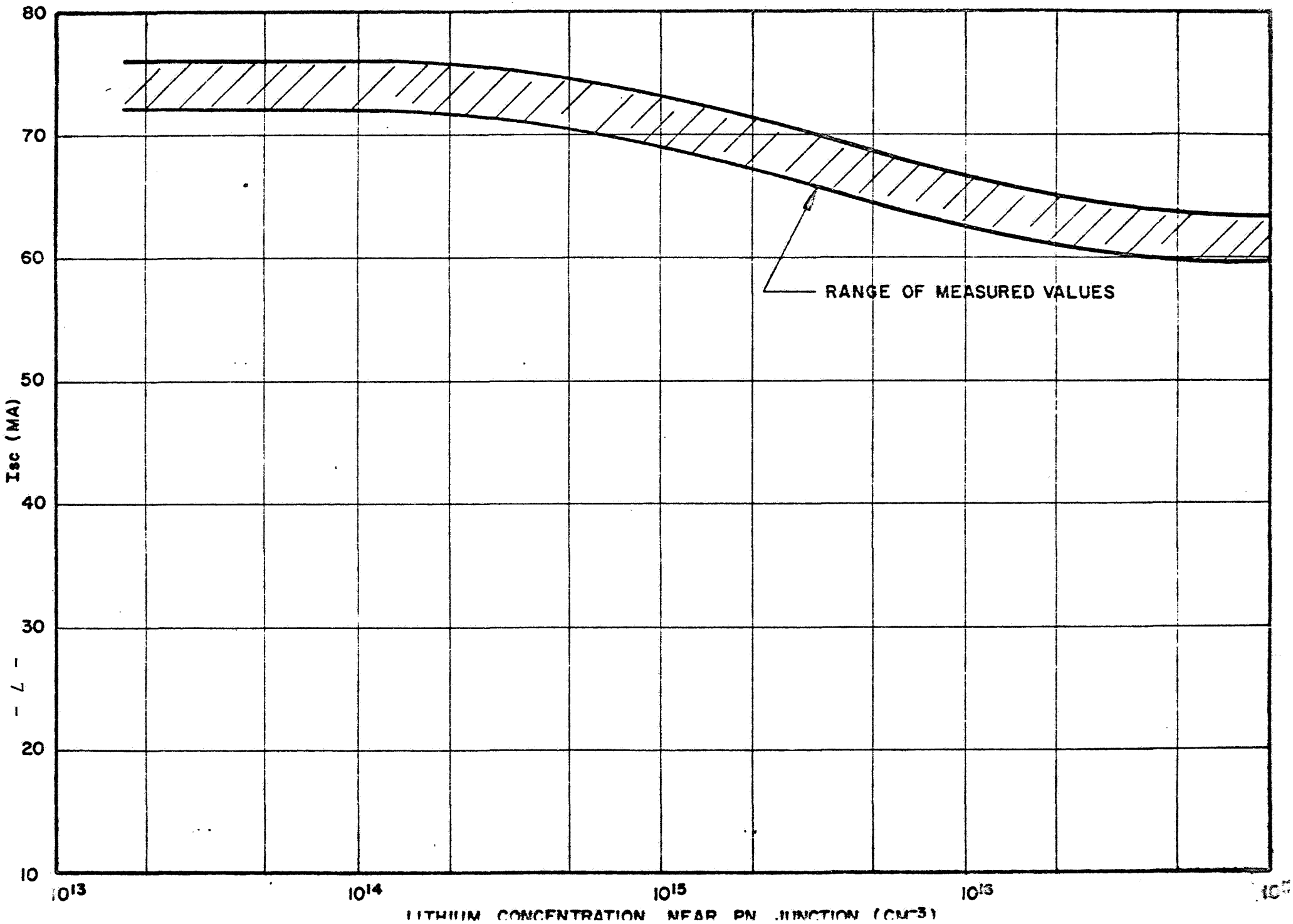


Figure 6. Isc versus relative mass of lithium obtained from integrating under concentration depth curves. Cell area 2 cm^2, space sunlight, 140 mw/cm^2.

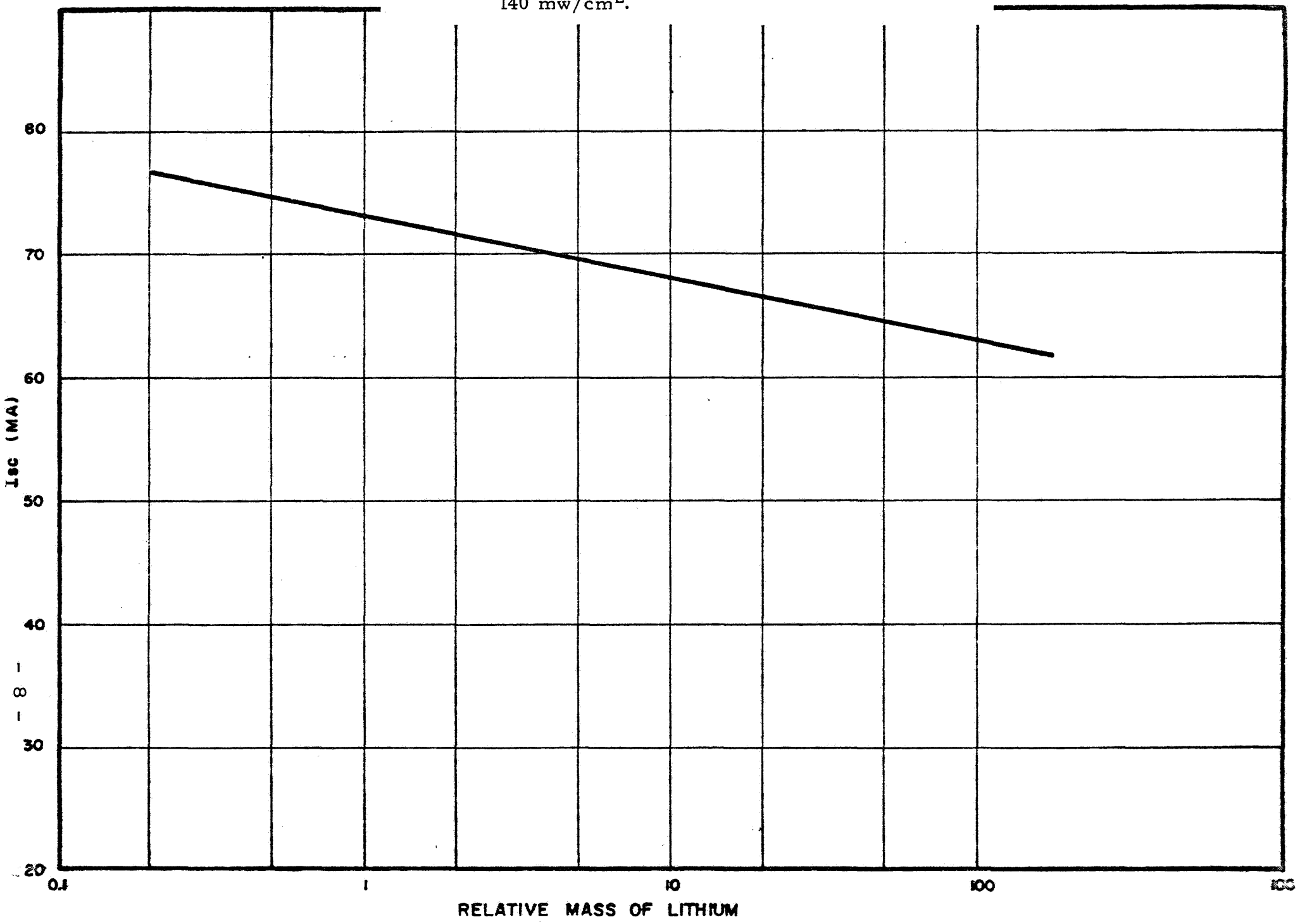
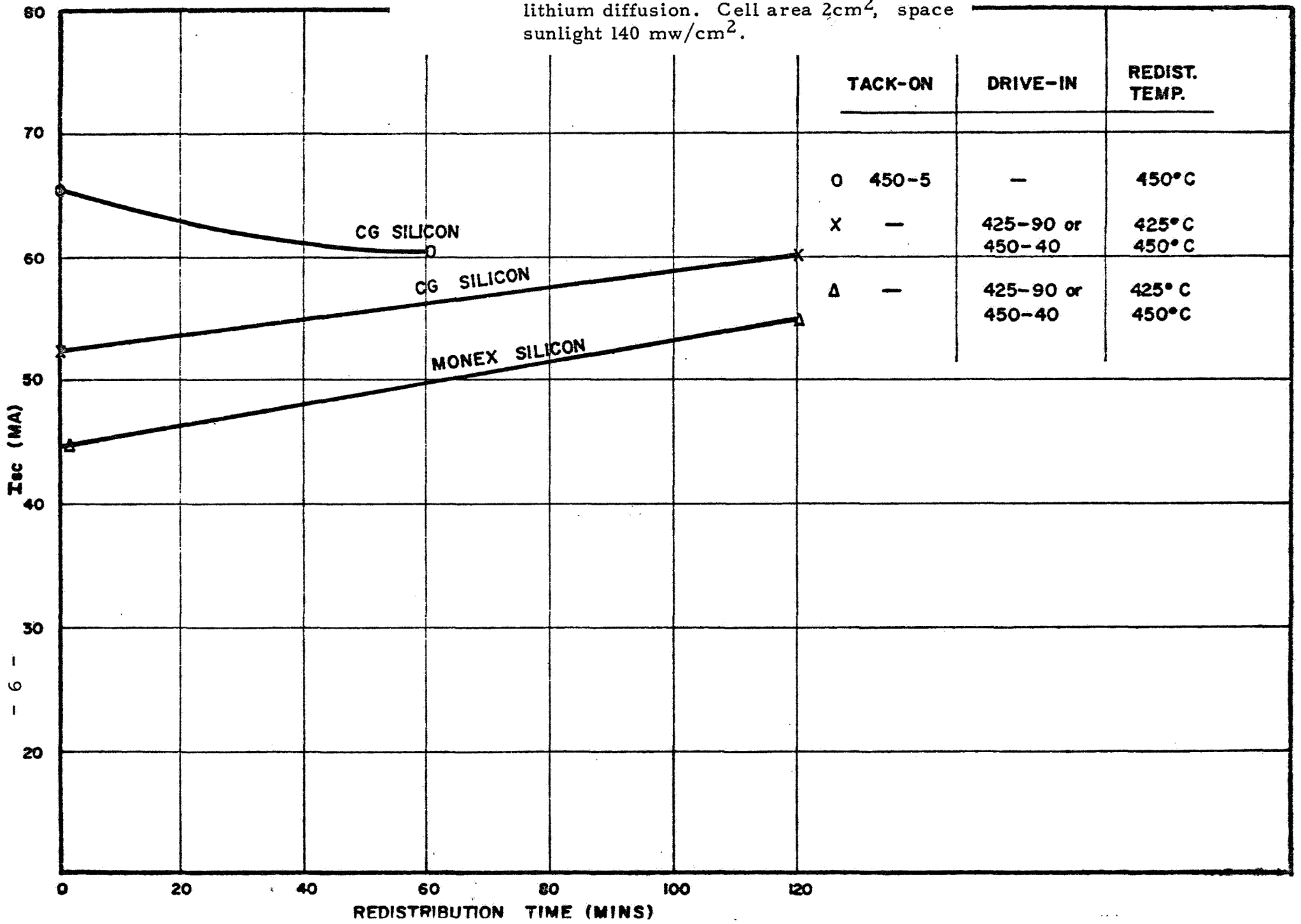


Figure 7. Isc as a function of redistribution time following either tack-on or drive-in lithium diffusion. Cell area 2cm^2, space sunlight 140 mw/cm^2.



2.3 LITHIUM DIFFUSION TESTS (Continued)

Diffusion at 450°C, followed by redistribution at 1050°C led to almost complete loss of measurable lithium. After redistribution, the perfection of the silicon recovered to the level measured before the 450°C diffusion.

2.4 DIFFERENT SILICON FORMS

The method used to grow the silicon crystals can have a marked effect on lithium cells. Before lithium is introduced, cells made from the various forms have comparable properties. However, after similar lithium diffusion schedules, crucible grown silicon generally gives cells with higher I_{SC} and V_{OC}, with corresponding increase at maximum power. The differences are shown in Table I.

TABLE I. AMO, 2 cm^2 Cells

Lithium Diffusion Schedule	Monex, Lopex or Float-Zone Silicon		Crucible Grown Silicon	
	I_{SC} (mA)	V_{OC} (mV)	I_{SC} (mA)	V_{OC} (mV)
425°C - 90 min. + 0 min. redist.	54.3	560	63.0	590
425°C - 90 min. + 60 min. redist.	59.4	555	65.0	590
425°C - 90 min. + 120 min. redist.	65.0	550	68.5	585
450°C - 40 min. + 0 min. redist.	54.8	560	62.0	600
450°C - 40 min. + 80 min. redist.	63.5	550	69.0	580

2.4 DIFFERENT SILICON FORMS (Continued)

These differences become less pronounced for longer redistribution times. The differences are still found even when the different forms of silicon have undergone simultaneously, the same boron diffusion, antireflective coating and lithium diffusion.

Other electrical measurements on the cells are as expected from the AMO I-V characteristics. Figure 8 shows the envelope of the dark diode forward characteristics for two forms of silicon, with the diffusion cycle shown. Figure 9 shows A-value plots for cells with no lithium, and then for the same lithium cycle. The differences are seen to extend down to low light levels. Extrapolation of those curves to $V_{OC} = 0$ show that crucible grown silicon has higher saturation current than the other forms.

Measurement of the lithium concentration profiles does not explain the differences. Generally, crucible grown silicon has more lithium through the cell, and as shown above, the higher concentration near the PN junction should decrease I_{SC}, opposite from the differences seen here. In agreement with the profile measurements, the surface concentration of lithium for crucible grown silicon is generally about double that for the other forms.

These results are not easily explained by other obvious differences in the ingots, such as for crucible grown ingots, resistivity is lower, and their oxygen content is much higher. The V_{OC} differences are puzzling, particularly in the slow variation for oxygen-lean silicon over a wide range of lithium distribution. More work is needed to explain the differences resulting from the different forms of silicon.

2.5 OTHER TOPICS

Work continued on applying aluminum contacts to lithium doped cells, with some success in equaling the electrical output obtained with titanium - silver contacts.

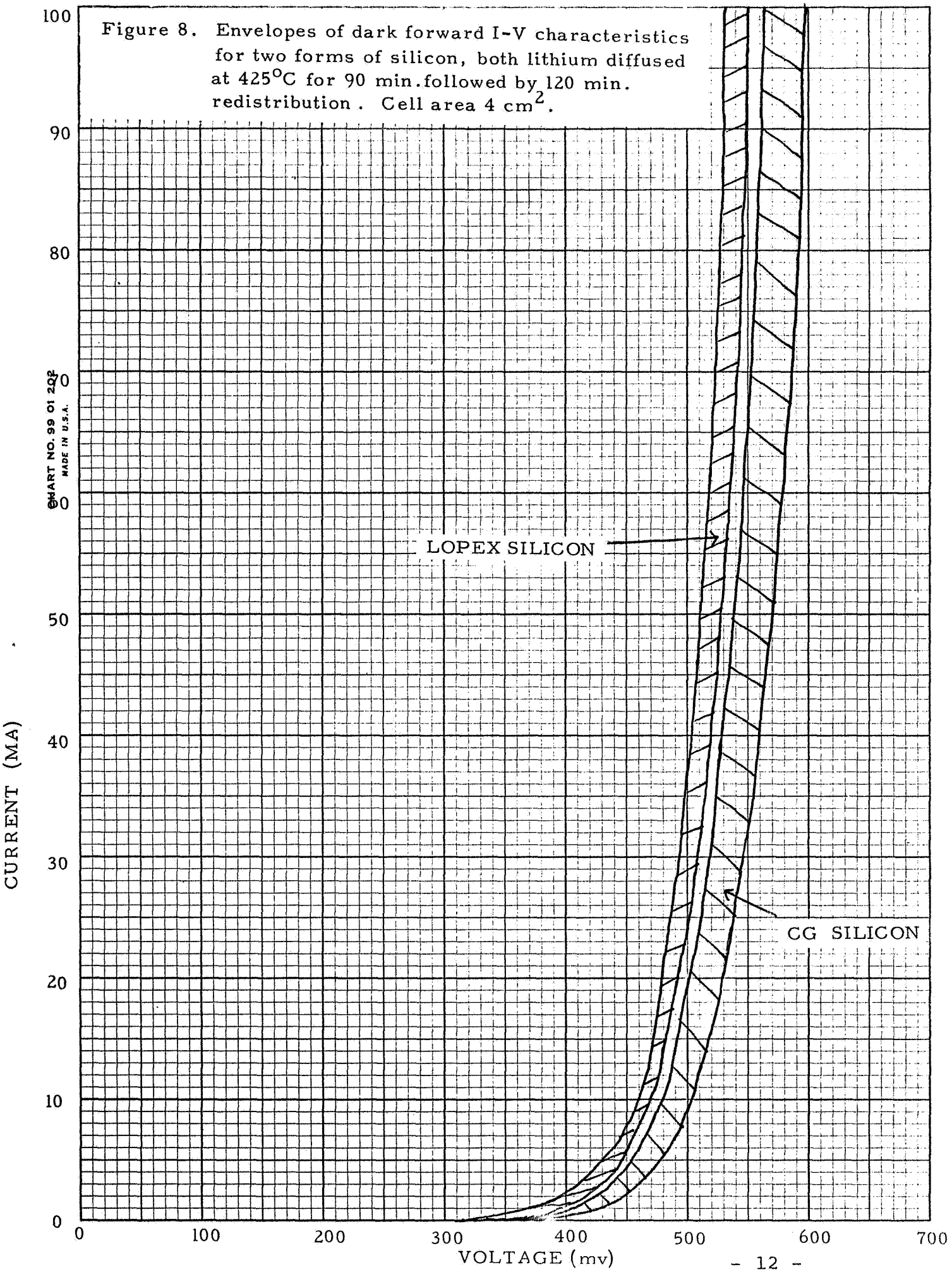


Figure 8. Envelopes of dark forward I-V characteristics for two forms of silicon, both lithium diffused at 425°C for 90 min. followed by 120 min. redistribution. Cell area 4 cm².
LOPEX SILICON
CG SILICON
CURRENT (MA)
VOLTAGE (mv)
0
10
20
30
40
50
60
70
80
90
100
0
100
200
300
400
500
600
700
CHART NO. 99 01 202
MADE IN U.S.A.

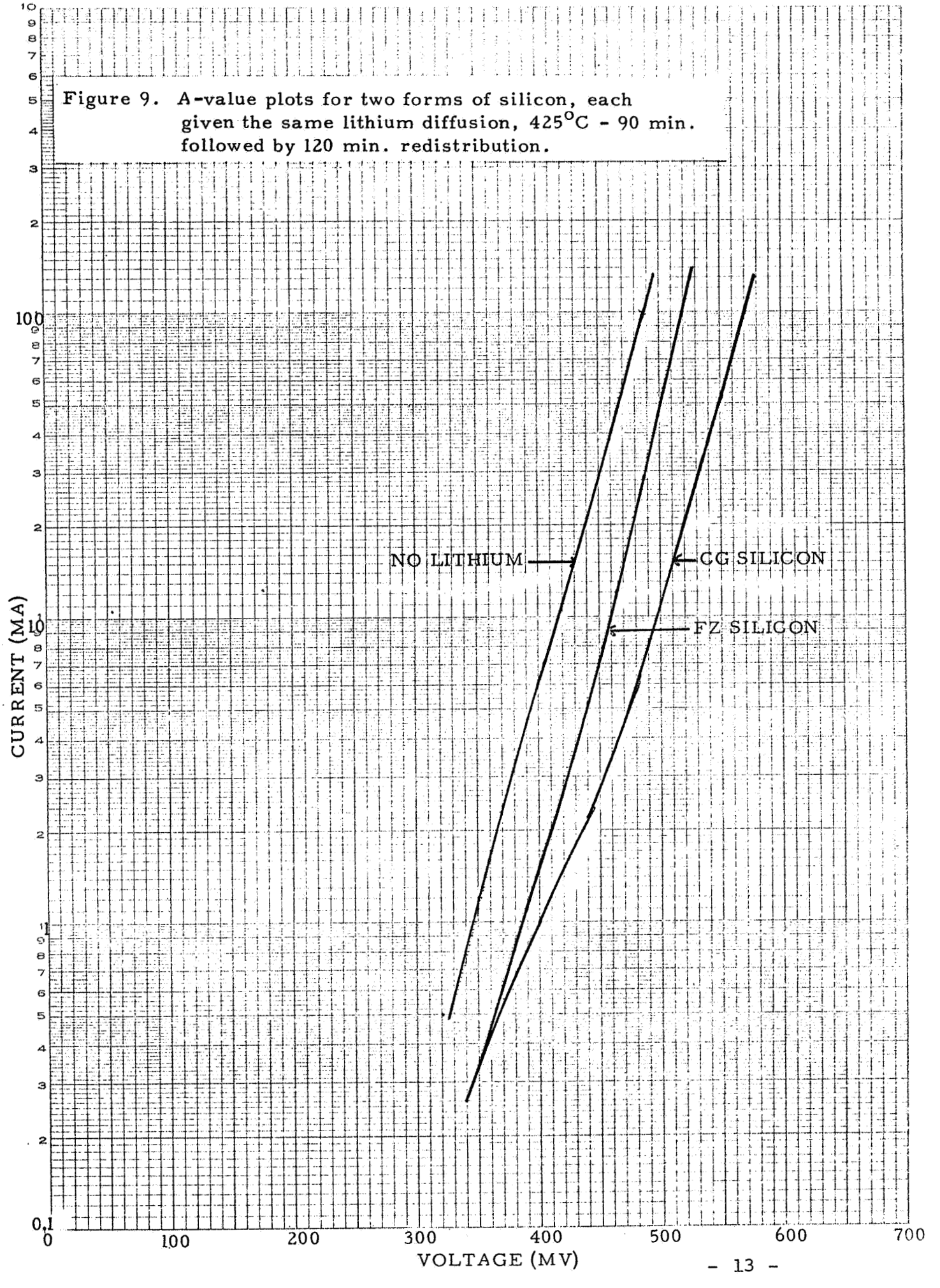


Figure 9. A-value plots for two forms of silicon, each given the same lithium diffusion, 425°C - 90 min. followed by 120 min. redistribution.

2.5 OTHER TOPICS (Continued)

A paper entitled "Effects of Lithium on Solar Cell Properties", which incorporated some of the work performed under this contract, was presented at the Seventh Photovoltaic Specialists' Conference.

2.6 CELL SHIPMENT DETAILS

One cell shipment of sixty (60) cells was made.

Cell Numbers: C4-1 through C4-60

Silicon: Monex*, 111 orientation, probably phosphorus doped, resistivity 100 ohm-cm.

Lithium Diffusion: Paint-on, five different schedules.

Cell No.	Drive-In	Redistribution
C4-1 to C4-12	425°C - 90 min.	None
C4-13 to C4-24	425°C - 90 min.	425°C - 60 min.
C4-25 to C4-36	425°C - 90 min.	425°C - 120 min.
C4-37 to C4-48	450°C - 40 min.	None
C4-49 to C4-60	450°C - 40 min.	450°C - 80 min.

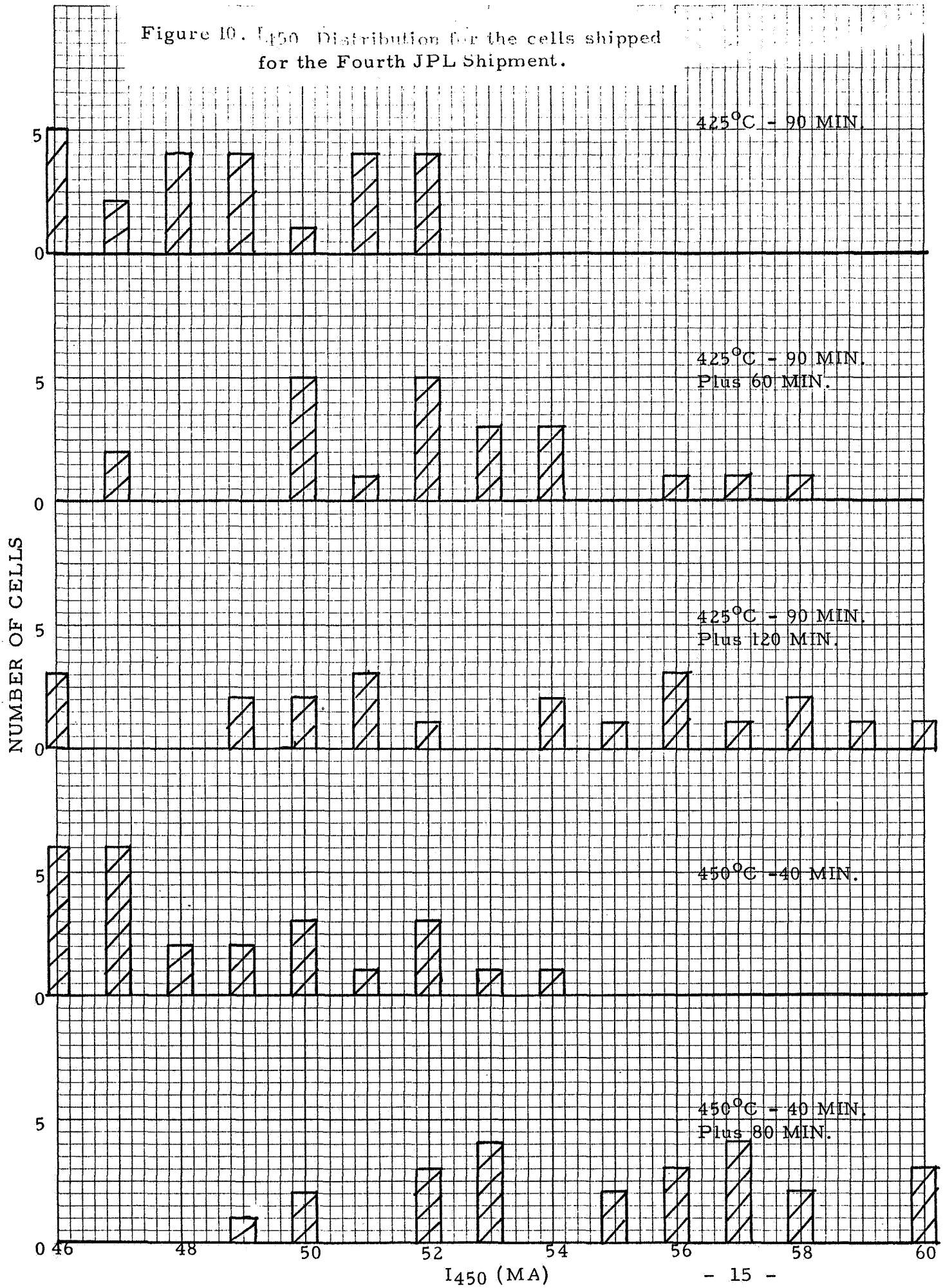
Cell Properties: (AMO, 140 mW/cm^2, cell size 2 cm^2).

Cell No.	I_{sc} (mA)	I_{450} (mA)	V_{oc} (mV)
C4-1 to C4-12	54.3	50.6	558
C4-13 to C4-24	59.4	54.9	557
C4-25 to C4-36	65.1	53.2	556
C4-37 to C4-48	54.8	50.2	554
C4-49 to C4-60	63.5	57.2	550

Most of the loss in I_{sc} was in long wavelength response. Figure 10 shows the I_{450} values for the 117 starting slices. The spread is greater than that found for crucible-grown silicon with the same lithium diffusion schedules. Figure 11 shows the cumulative percentage of I_{450} values for the five groups.

* Trademark of Monsanto Chemical.

Figure 10. I_{450} Distribution for the cells shipped for the Fourth JPL Shipment.



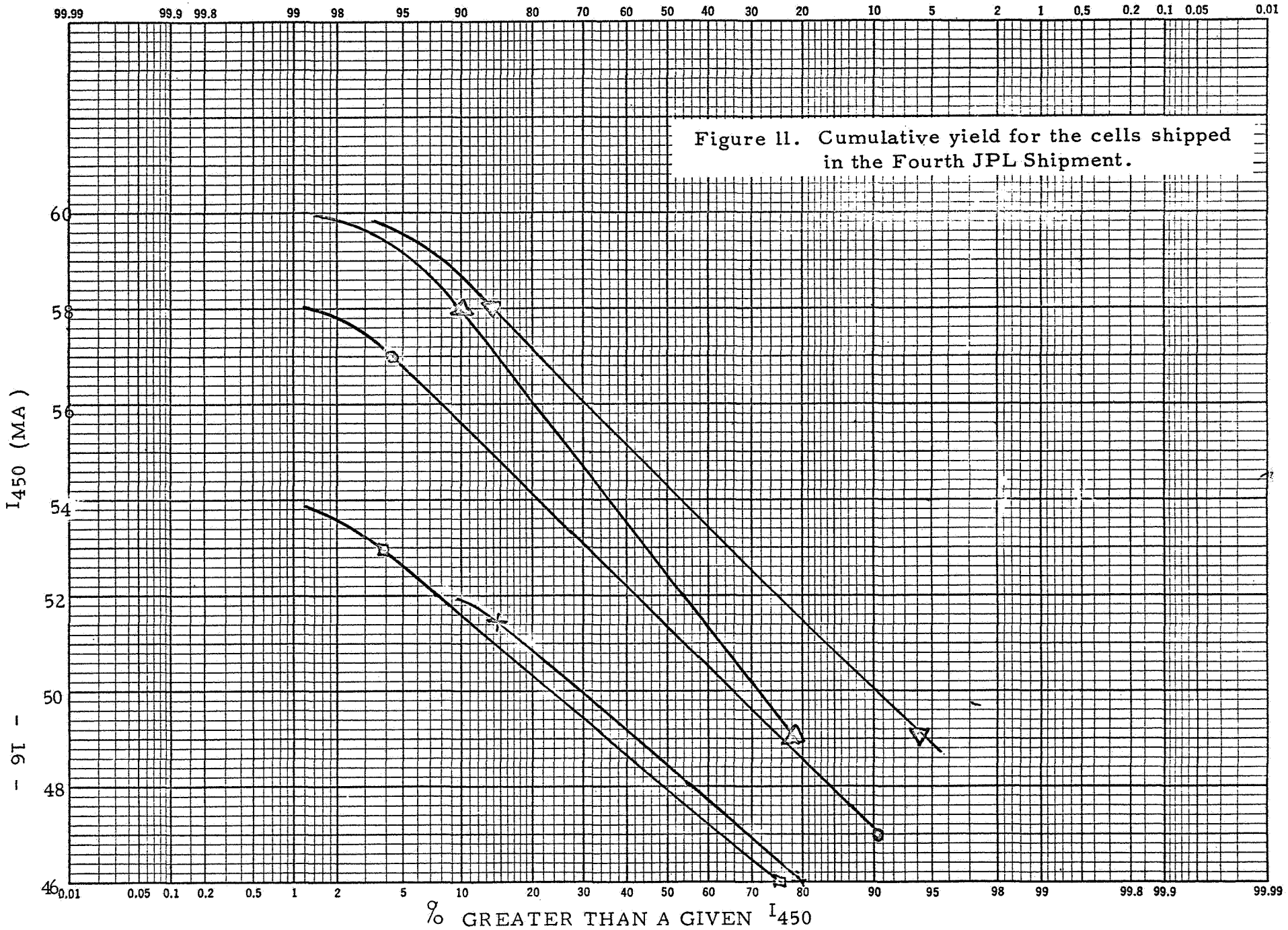


Figure 11. Cumulative yield for the cells shipped in the Fourth JPL Shipment.

2.6 CELL SHIPMENT DETAILS (Continued)

Lithium Distribution: Figure 12 shows the lithium distributions measured by resistance probe for the various diffusion conditions. In general, the I_{SC} values fall into the sequence expected from the lithium concentration near the front surface.

3.0 CONCLUSIONS

There is still a need to improve the methods from introducing lithium into silicon, particularly to develop methods capably of scaling-up. In this period, more understanding was gained of the effects of different lithium diffusion cycles. There is a definite difference in the behavior of different forms of silicon, and the reasons for the difference are not clear at present.

4.0 RECOMMENDATIONS

In the next quarter effort will be applied to understand the effect of lithium on cells made from different forms of silicon.

5.0 NEW TECHNOLOGY

None

Figure 12. Lithium Distribution Typical of Cells in Fourth JPL Shipment.